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Numerical Investigation of OAM Based Indoor Communication in a Corridor with Electrical Conducting Walls

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***Abstract*—This paper investigates the indoor communication of radio waves carrying orbital angular momentum (OAM) inside a rectangular corridor, that has electrical conducting walls. The method of moments (MoM) is employed in this study for the modeling of a uniform circular array (UCA) and a rectangular corridor. The UCA consists of eight dipoles and a reflecting ground. A transmitting UCA (Tx) and a receiving UCA (Rx) are located at two ends of the corridor. Standard scattering parameters are exported from the full-wave simulation and further used to calculate the wireless communication between Tx and Rx using mixed modes. Comparing to the free space case, the possibility of indoor wireless communication of OAM waves is investigated. Specifically, the transmission of different OAM modes with regard to communication distances and location is numerically explored.**

***Index Terms*—Indoor communication, method of moments (MoM), orbital angular momentum (OAM), wireless communication.**

I. Introduction

Wireless communication of radio waves carrying orbital angular momentum (OAM) has been proposed recently to boost the data rates in optics and microwave domains [1]–[5]. Uniform circular arrays (UCAs), such as dipole arrays [5]–[7], are usually used to transmit and receive OAM waves.

Although OAM based communication has been experimentally tested [2], there are still a lot of fundamental issues to be resolved. Most of the research on OAM waves like [5]–[7] is conducted in the free space. Interference on OAM based communication from simple conducting plates [8] and infinite ground plane [9] were discussed before. In this paper, a more complicated environment, a rectangular corridor, is studied for indoor communication of OAM waves. Mixed-mode scattering matrices [10], [11] are utilized to calculate the transmission of different OAM modes between the transmitting UCA (Tx) and receiving UCA (Rx). The full-wave simulation is carried out by a method of moment (MoM) based tool [12].

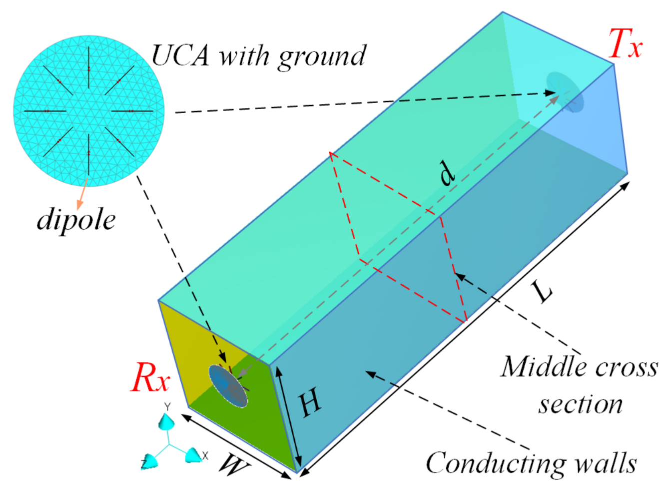


Fig. 1. Illustration of the indoor communication environment. Two uniform circular arrays (UCAs) are inside a rectangular corridor, one transmitter and one receiver.

II. Communication Configuration

As illustrated in Fig. 1, two OAM arrays are located in a rectangular corridor consisting of electrical conducting walls. Two OAM arrays (Tx and Rx) are originally set at the center of the corridor ends and face to face.

A. Uniform Circular Array

Eight linear dipoles with a length of 27.4 mm and a diameter of 0.2 mm are arranged radially in a circular array. The array diameter from inner dipole ends is 30 mm. A circular PEC ground plane is introduced as a reflector, of which the diameter is 100 mm. These eight dipoles are located 15 mm above the ground. The UCA operates at the center frequency of 5.0 GHz

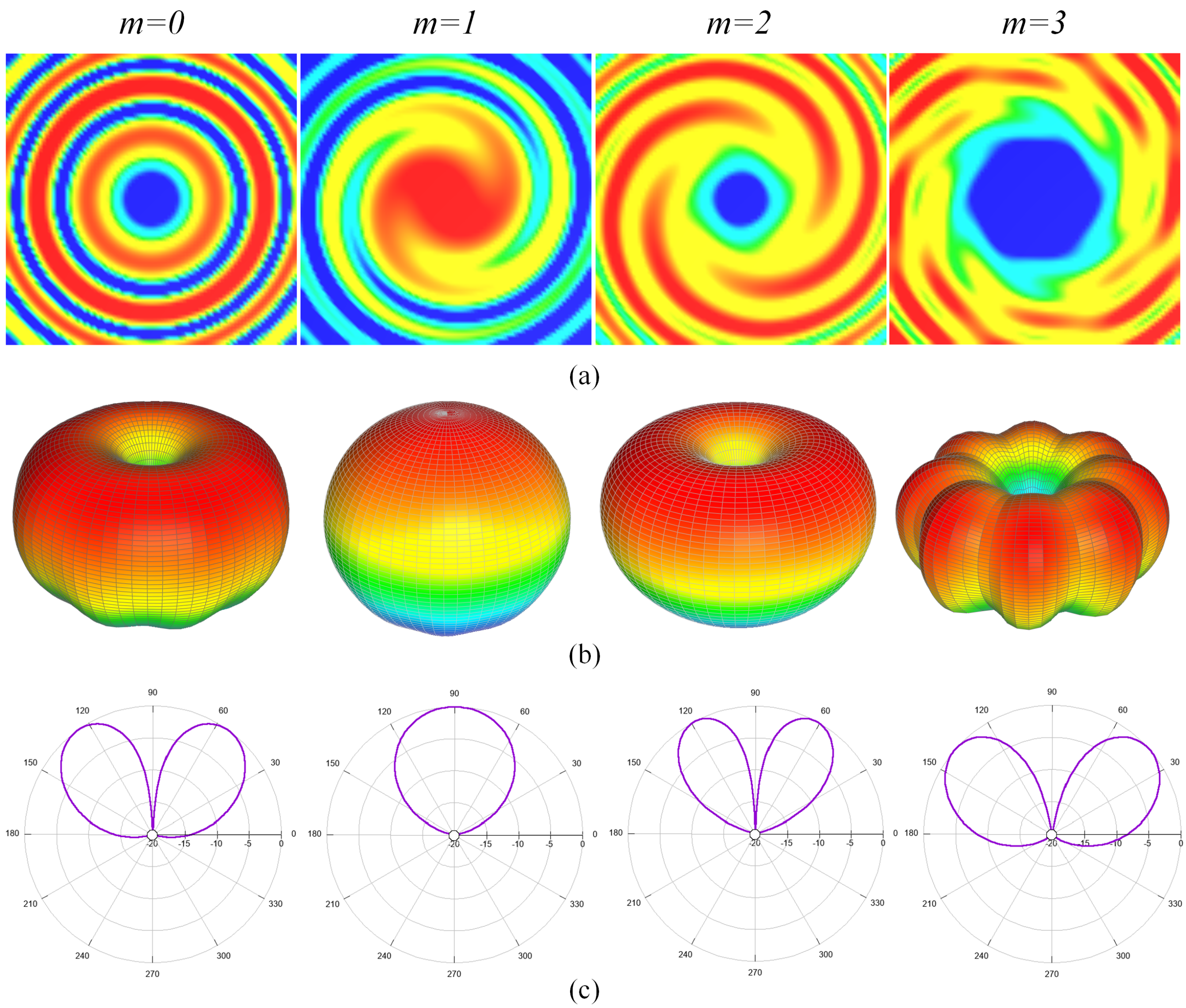


Fig. 2. Electric fields distributions (a), 3D radiation patterns (b) and 2D radiation patterns (c) at 5.0 GHz of the studied UCA in different modes in the free space.

in this paper. Ten basic functions are assigned on each dipoles in MoMs.

Fig. 2 shows the characteristics of the studied UCA (Tx or Rx), which would be helpful for further understanding of the OAM wave communication. With the ground, the OAM waves propagate in one forward direction (+z direction: θ=90°), which can be seen from the radiation patterns.

B. Rectangular Corridor

To simplify the problem, the corridor is modeled as a perfect electrical conductor (PEC), with two open ends. Its dimension $W \times H \times L$ as marked in Fig. 1 is $300 \times 300 \times 1000$ m^3. To achieve good numerical convergence, the mesh size of the corridor is $1/7\lambda$, whereas $1/10\lambda$ is for the dipole and the ground. λ is the wavelength of the operating frequency in the free space.

III. Communication Performance

The full-wave simulation is carried out in a MoM code [12] for both the Tx and Rx OAM arrays and the rectangular corridor. Different communication distances inside the corridor and different heights of Rx have been studied in this numerical investigation.

A. Electric Field Distributions

The distributions of electric fields in the center cut of the rectangular corridor are plotted in Fig. 3. In this plot, only the Tx is excited with proper OAM modes whereas the Rx is matched to 50 Ohm.

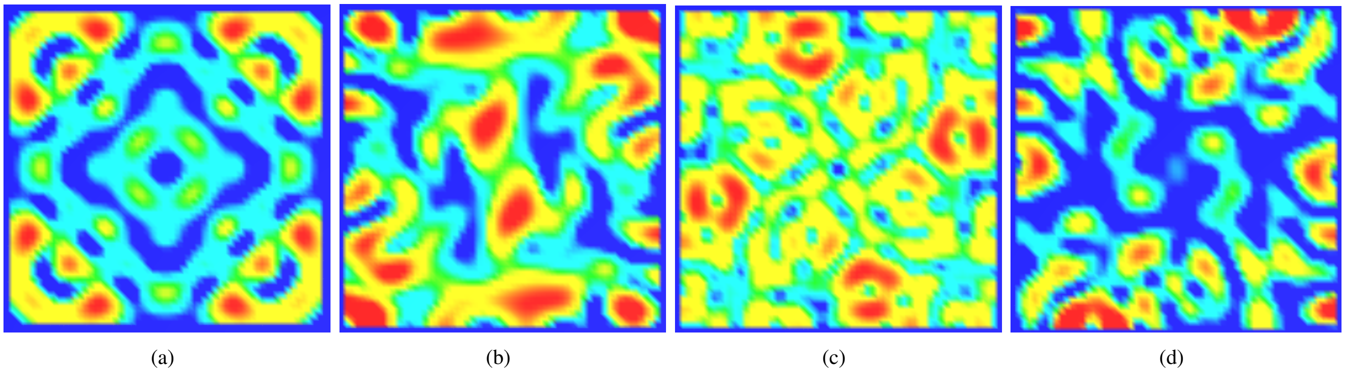


Fig. 3. Electric fields distributions on the cross section in the middle of the corridor (Fig. 1). (a) mode 0 is transmitted from Tx, (b) mode 1 is transmitted from Tx, (c) mode 2 is transmitted from Tx and (d) mode 3 is transmitted from Tx.

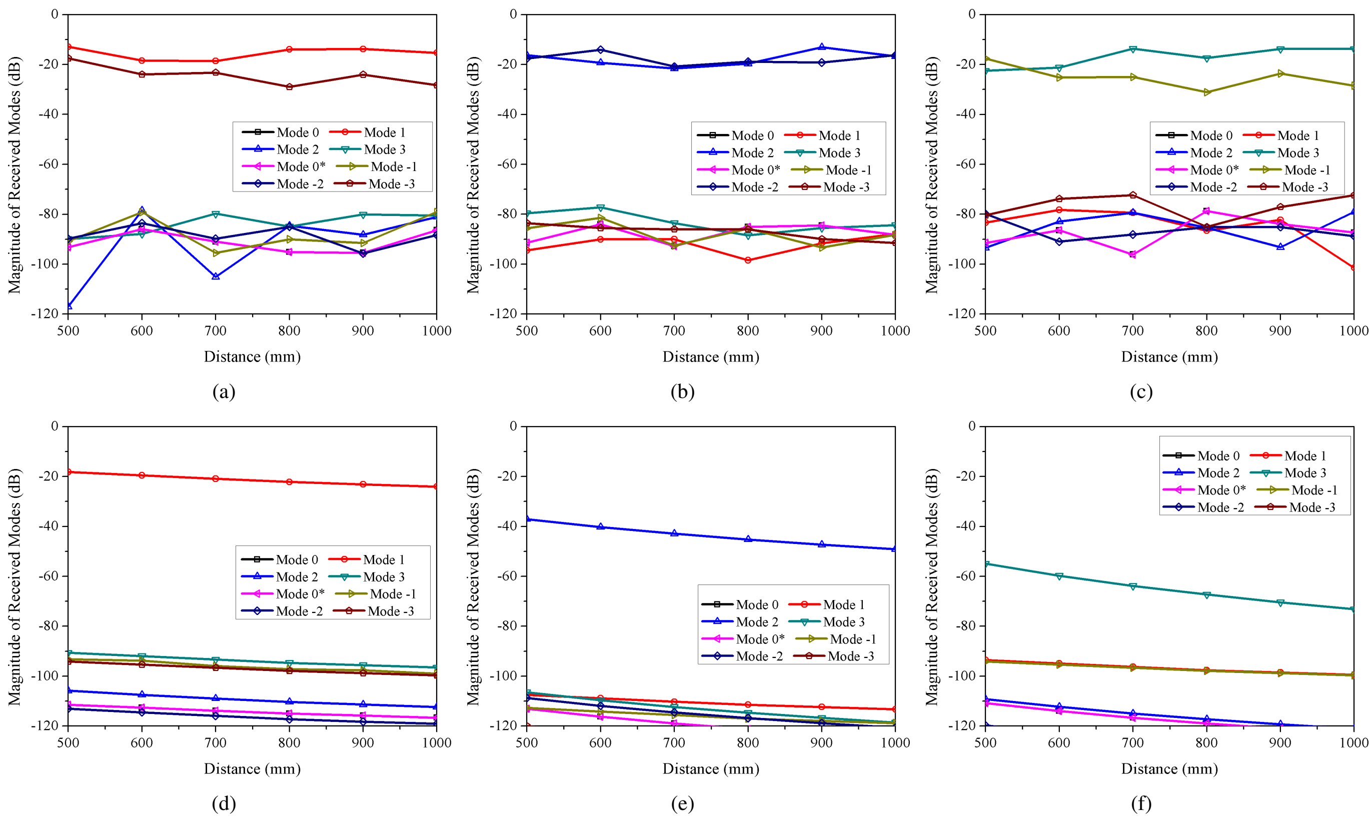


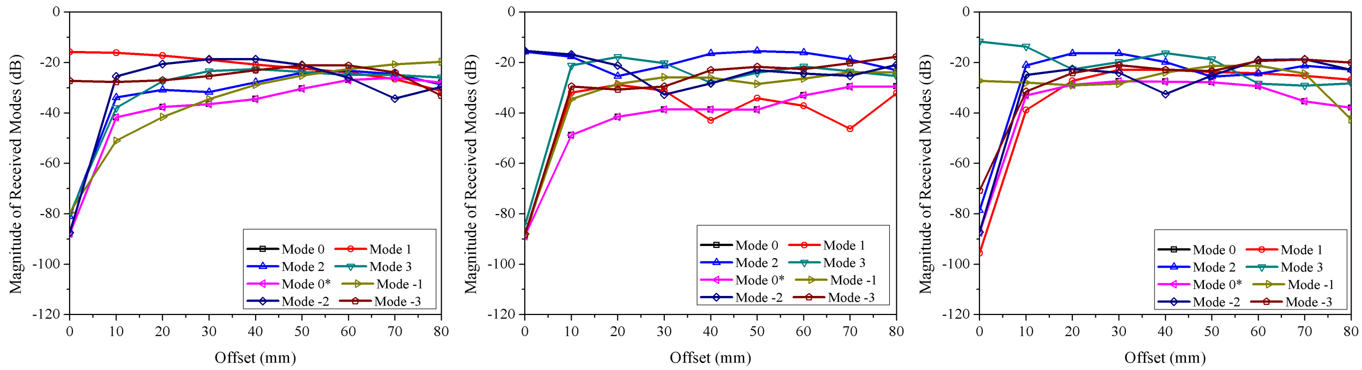
Fig. 4. Magnitudes of received OAM modes when different modes are transmitted from Tx. (a) and (d) when only mode 1 is transmitted from Tx, (b) and (e) when only mode 2 is transmitted from Tx, (c) and (f) when only mode 3 is transmitted from Tx, (a-c) are the cases in the rectangular corridor, whereas (d-f) are in the free space.

It is obvious that the vortex patterns shown in the first row of Fig. 2 have been dramatically changed, due to the superposition of multiple reflections from the corridor walls. Moreover, unlike the conventional electric distribution as in Fig. 3(a), the OAM waves' patterns are not symmetric.

B. Communication versus Distance

From the electric fields in Fig. 3 it is not possible to draw conclusions on OAM based indoor communication just yet. Thus, mixed-mode scattering matrices [10] are taken to present the communication of OAM waves. In this section, the communication distances d vary from 500 mm to 1000 mm as shown in Fig. 4. Furthermore, corresponding mode communications in the free space are also given for comparison.

Figs. 4(a, b and c) show that there are additional noise modes received at Rx, where noise modes are defined as $\mathbf{M_{TR}}$(i, j) [10], i≠j. For instance in Fig. 4(a), the mode -3 has been increased from -95 dB to around -30 dB, when mode 1 is transmitted at Tx. The noise modes are in inversely vortex directions comparing to the transmitted modes, such as



(a) (b) (c)

Fig. 5. Magnitudes of received OAM modes when different modes are transmitted from Tx, when Tx and Rx are at different location (e.g. height). (a) only mode 1 is transmitted from Tx, (b) only mode 2 is transmitted from Tx, (c) only mode 3 is transmitted from Tx.

-3 mode for mode 1, -2 mode for mode 2 and -1 mode for mode 3. Apart from these inverse noise modes, the other noise modes remain very low.

Compared to the free space case, it is found that the magnitude of the dominant modes like the received mode 1 when mode 1 is transmitted $\mathbf{M_{TR}}(1, 1)$ has been enhanced, especially for the high-order modes as $\mathbf{M_{TR}}(2, 2)$ and $\mathbf{M_{TR}}(3, 3)$. $\mathbf{M_{TR}}(3, 3)$ has been increased from -70 dB to -15 dB at the distance of 1000 mm.

C. Communication versus Height

An additional exploration is implemented with respect to the height of the OAM arrays, because the electric fields are stronger at the edge than the center. The Rx array is shifted from the corridor-end center to 80 mm away to the edge, whereas Tx array is fixed at the original center.

Fig. 5 presents communication of different OAM modes when the mode -1, -2 and -3 are transmitted separately. It is observed that the center location is still the best for the dominant-to-noise mode ratio, which is the same as the case in the free space. The offsets between the Tx and Rx arrays make all the modes mixed together at Rx and difficult to distinguish.

IV. Conclusion

This paper investigated the OAM mode communication in a rectangular PEC corridor instead of the ideal free space. The numerical results indicate that the received signals of the dominant OAM modes can be enhanced due to the PEC corridor environment. Moreover, the dominant mode remains its magnitude well over different distances, implying that the long distance propagation of OAM modes in the corridor is possible. However, due to the exist of the corridor, an inversely vortex mode increased significantly as noises. The findings in this paper are not limited to the specific dipole antenna arrays, and can be applied to other antenna arrays and frequencies. The studied OAM dipole-array is taken as a simple example without optimization. Better communication performance could be obtained using an optimized OAM array.

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